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Rare plants in the Golden Gate Estuary (California): the relationship between scale and understanding

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Abstract. We analysed 10 rare-plant projects conducted from 1982 to 2005 for trends in scientific findings, project costs, effort and efficacy. Our purpose was to determine whether generalisations about these factors can be found, and if so, whether they might be useful for designing and implementing successful future rare-plant endeavours. Analysis results revealed that rare plant species persist despite their restriction to a highly fragmented and degraded urbanised estuary of more than seven million people. Also important were the findings that with sufficient funding, successful rare-plant reintroduction is possible in the short-term at minimum. Habitat considerations, however, are paramount—i.e. habitat requirements of a rare species should be known before reintroduction for the restoration effort to be likely to be successful. Understanding ecosystem functions that support rare species, therefore, remains the highest priority for rare-plant restorationists. Project costs varied significantly, as expected, but a ‘middle ground’ provides necessary and sufficient funding to conduct most rare-plant work for one or a few species. Costs rise, but not linearly, when additional rare taxa are included. Given our experience is applicable elsewhere, taking an ecosystem approach to protection of rare flora is most successful and cost effective.

Introduction

Objectives

A healthy literature on the phenomenon of biological rarity has developed during the latter half of the 20th century. While the formative statements for conservation of rare plants in the 21st century arose from the mathematical foundations of modern ecology (e.g. Preston 1948, 1962), more recent literature has focused on finding geographic, taxonomic or ecological patterns of rarity, particularly those illuminated by comparisons of rare and common species (e.g. Rabinowitz 1978; Kunin and Gaston 1997). Researchers also have focused on the causes of rarity (e.g. Fiedler and Ahouse 1992; Yates *et al.* 2007), because understanding why something is rare may provide valuable insight in how to prevent extinction. The interaction between the biological trait of rarity and the process of extinction has, since Darwin first described their linkage (Darwin 1872), been a focus of modern conservation biology.

The growing body of research on rare organisms, highlighted in this special volume, suggests that we must now look for patterns not only related to the intrinsic biological phenomenon, but also about the research itself. Of particular relevance are practical questions, such as ‘is habitat loss the primary cause of naturally rare species in a heavily urbanised estuary, or is an intrinsic life history feature more probable’ or ‘when time, resources and funds for field and laboratory study are limited, what are the critical features to examine to protect a rare species’? Or even less sanguine ‘when, if ever, is it not worth the cost to look for a rare species that may well be extinct in a highly fragmented, heavily populated environment’?

The present paper addresses many of these questions related to conservation of rare plants, by conducting a retrospective on nearly 25 years of research on rare plants in the Golden Gate Estuary of California. The projects examined herein range from very short-term to moderately long-term, from well funded to inadequately funded, from multi-species to single-species projects, and from those concerning a very small geographic area to those concerning several thousand square kilometers of rare-plant habitat.

Study area and rare plant taxa

The Golden Gate Estuary (Fig. 1) (also known as the San Francisco Estuary (Estuary)) is the terminus of the Sacramento–San Joaquin drainage system, an area roughly 424 000 km^2 or 40% of the state of California (San Fransisco Esturary Project 1991). Governed by nine county jurisdictions in addition to state and federal jurisdictions, the Estuary supports ~6.8 million

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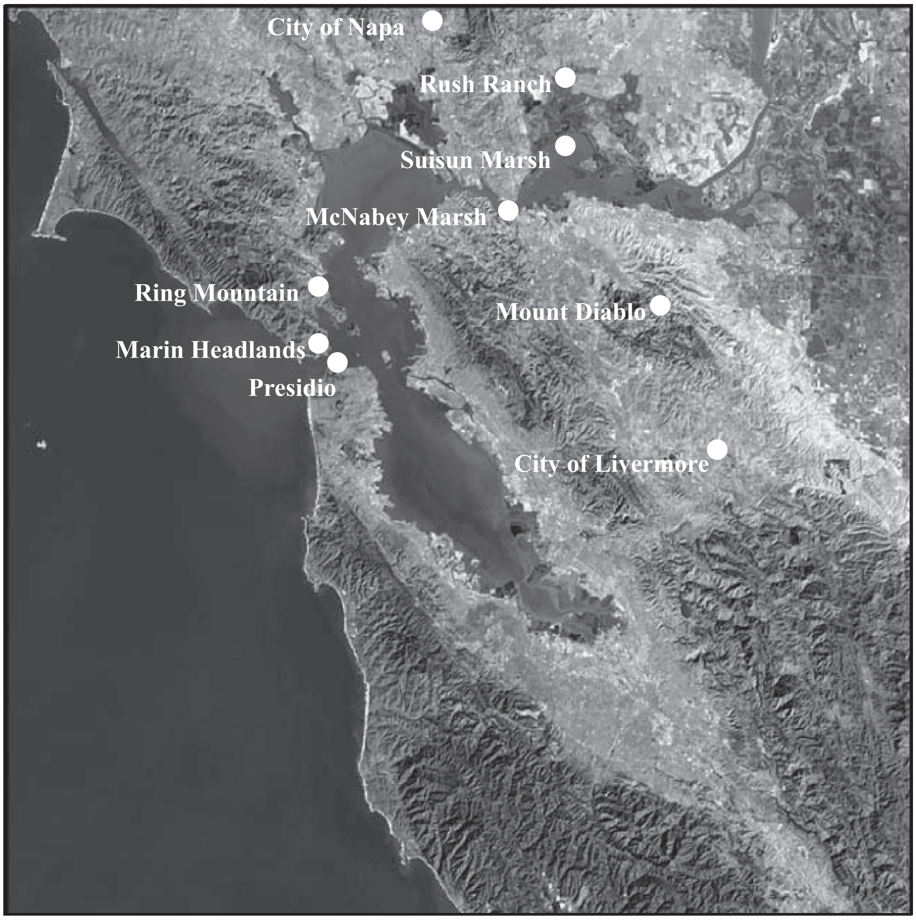

Fig. 1. Map of the nine highlighted projects within the Golden Gate Estuary.

people (US Census Bureau 2004). The study area includes watersheds of the San Francisco Bay, Suisun Marsh and the Sacramento–Joaquin Delta. The Golden Gate Estuary is the largest estuary on the west coast of both North and South America (San Francisco Estuary Project 1991).

Since 1978, we have had the opportunity to work within numerous watersheds throughout the Estuary on a variety of rare-plant projects. These projects have ranged in scope from mapping the vegetation history of the paleoendemic California coast redwood (*Sequoia sempervirens*) at Muir Woods National Monument to field surveys for a recently rediscovered 'extinct' neoendemic thistle (*Cirsium hydrophilum* var. *hydrophilum*). Not all of the projects in which we have been engaged over the last three decades are included in the analysis, however. We have chosen 10 different projects to serve as the database of our analysis, representing a broad range of goals, rare species, funding sources, levels of effort and project outcomes (Table 1). A total of 33 taxa, including 23 vascular plants, nine

Table 1. Golden Gate Estuary Rare Plant Project details (1983–2005)

Project	Total cost US$	Total cost AU$	Total cost £	No. of years	Area (ha)	No. of target species	No. of collateral species	No. of field crew
Ring Mountain	20 000	26 400	11 400	2	150	1	6	1
Restoration & recovery of Mason's lilaeopsis	180 000	237 600	102 000	4	18 211	1	3	3
Napa River/Napa Creek Flood Control Project	120 000	158 400	68 000	5	9	2	1	3
GGNRA Parks – Franciscan thistle	4000	5300	2300	(<1)	20	1	0	2
Reintroduction of soft birds beak	178 600	235 800	101 300	2	892	1	0	4
Springtown wetlands	36 000	47 500	20 400	(<1)	109	1	0	2
Rush Ranch – Suisun thistle	40 000	52 700	22 800	(<1)	425	1	1	3
Species diversity in northern California salt marshes	20 300	26 800	11 500	4	14	1	0	1
San Jose *Endangered Species*	50 000	65 900	28 500	(<1)	1012	6	2	2
Solano County Endangered Species Program	20 500	27 000	11 600	1	275	1	4	1

vertebrates and one invertebrate represent the array of study organisms (Table 2).

The remainder of this paper has been organised into three parts. The first provides a very brief overview of 6 of the 10 rare-plant projects. Our purpose here is to provide a minimum background for all projects in our analysis. The second part represents a detailed look at three projects chosen to illustrate in detail the range of rare-plant projects in this dataset. The third and final part details a summary of our insights gained as a result of these projects, and this retrospective. First, however, we believe it important to examine briefly the concept of rarity to ensure consistency in our understanding of the meanings of rarity used herein and throughout this special issue.

Rarity

Vascular-plant rarity is an intrinsic biological property defined most simply by geographic distribution and population abundance (Drury 1974, 1980; Fiedler 1986, 1995; Fiedler and Ahouse 1992). The following three different phenomena are represented by the intersection of these traits: (a) geographically restricted but characterised by large population sizes, (b) geographically widespread but characterised by sparse populations and, (c) geographically restricted with small population size. However, biological species exist in evolutionary as well as ecological time, and thus a third axis can be used to further refine the concept of rarity. A three-dimensional graph elucidates well-recognised evolutionary entities such as paleoendemics (i.e. relatively old taxa with limited geographic distribution) and neoendemics (i.e. relatively newly evolved taxa with limited geographic distribution) (Fig. 2).

An important refinement of the concept of rarity during the late 1970s and early 1980s that tied the phenomenon of rarity to plants (as well as other more or less sessile organisms) was the recognition of habitat specificity, not evolutionary history (Rabinowitz 1981). By describing rare organisms by geography, population abundance and habitat specificity, Rabinowitz (1981) identified 'seven forms of rarity'. Noteworthy, however, is that by using this taxonomy, Rabinowitz and her colleagues revealed important life-history characteristics of certain types of rarity, and patterns of community structure in North American prairie ecosystems (Rabinowitz 1978; Rabinowitz *et al*. 1979,

Table 2. Thirty-three rare taxa (23 plant species, nine vertebrates, one invertebrate) in the Golden Gate Estuary Rare Plant Projects (1983–2005)

Vascular plant species	Vertebrate species
Family: Apiaceae	Family: Ambystomatidae
Lilaeopsis masonii	*Ambystoma californiense*
Family: Asteraceae	Family: Cricetidae
Aster lentus	*Reithrodontomys raviventris*
Cirsium andrewsii	Family: Emberizidae
Cirsium fontinale var. *campylon*	*Melospiza melodia samuelis*
Cirsium hydrophilum var. *hydrophilum*	*Melospiza melodia maxillaris*
Hemizonia congesta ssp. *lutescens*	Family: Emydidae
Lessingia micradenia var. *glabrata*	*Clemmys marmorata*
Family: Brassicaceae	Family: Rallidae
Streptanthus albidus ssp. *albidus*	*Laterallus jamaicensis coturniculus*
Streptanthus albidus ssp. *peramoenus*	*Rallus longirostris obsoletus*
Family: Crassulaceae	Family: Ranidae
Dudleya setchellii	*Rana aurora draytonii*
Family: Fabaceae	Family: Soricidae
Lathyrus jepsonii var. *jepsonii*	*Sorex ornatus sinuosis*
Family: Liliaceae	
Calochortus tiburonensis	Invertebrate species
Calochortus umbellatus	Family: Nymphalidae
Fritillaria liliaceae	*Euphydryas editha bayensis*
Family: Linaceae	
Hesperolinon congestum	
Family: Malvaceae	
Malacothamus hallii	
Family: Orobanchaceae	
Castilleja affinis ssp. *neglecta*	
Cordylanthus mollis ssp. *mollis*	
Cordylanthus palmatus	
Family: Poaceae	
Calamagrostis ophiditis	
Family: Polygonaceae	
Eriogonum luteolum var. *caninum*	
Family: Rhamnaceae	
Ceonothus ferrisae	
Family: Scrophulariaceae	
Limosella subulata	

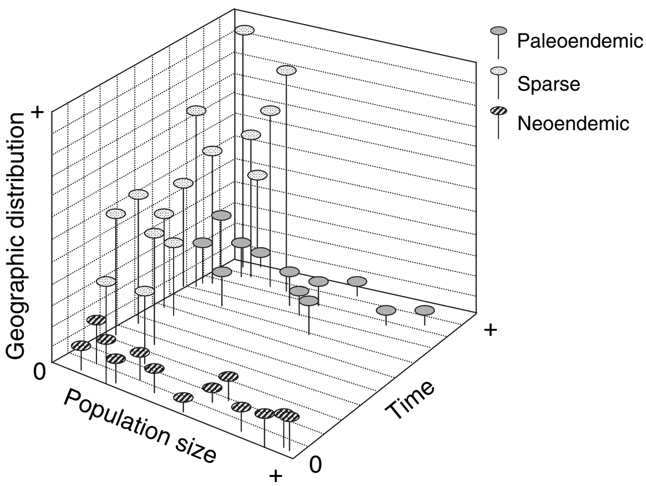

Fig. 2. Three axes of rarity depict paleoendemics and neoendemics in addition to sparse populations.

1984, 1989; Rabinowitz and Rapp 1981). Little progress has been made regarding the theories of rarity since this work. However, it is important to recognise two conservation-related issues as context for consideration of the rarity of a species. First, many species are rare today simply through habitat loss and degradation, regardless of their pre-European contact status (i.e. 'anthropogenic rarity'). Second, patterns and processes of natural rarity in north-temperate ecosystems should not be expected to hold true for megadiverse regions, such as the flora of the South-west Botanical Province of Western Australia (Hopper 1992). Thus, natural processes that cause rarity, and the functioning of rare species in megadiverse systems, appear to require mechanisms for understanding and explaining this biological phenomenon that are likely to be different than for either northern-temperate or wet-tropical ecosystems.

Project précises

Tiburon mariposa lily, Ring Mountain, upper watershed, 1983–1984

Ring Mountain Preserve is an isolated remnant of the perennial bunchgrasslands that once characterised a large portion of the upland landscape of the Estuary (Fiedler and Leidy 1987). The preserve is distinguished by its extensive ultramafic soil mosaics that support a highly endemic flora, including the highly localised endemic Tiburon mariposa lily (*Calochortus tiburonensis*, Liliaceae). This rare flora and the native bunchgrasses are typical of older and relatively more weathered ultramafic substrates.

In 1983, The Nature Conservancy gazetted the preserve, a 148-ha urban park on the summit of the Tiburon peninsula in Marin County, California. Shortly after establishment of the preserve, one of us (PLF) was retained to map the distribution of seven rare plant species, develop a list (and distribution map) of the most significant non-native invasive plants, and provide management recommendations for the rare flora. Fiedler conducted extensive surveys of the preserve over a 2-year period. Her work revealed an expanded distribution of all seven rare plant species, documenting increases in population size by three orders of magnitude greater than in previous records (Fiedler 1983–1984). Management recommendations resulted in further protection of the rare species and an expansion of the preserve.

Mason's Lilaeopsis: Sacramento–San Joaquin Delta/Suisun–North Bay tidal wetlands, 1992–1996

In April 1988, a leaking storage tank at the Shell Oil refinery in Martinez, California, drained ~400 000 gallons of crude oil into an adjacent creek, which subsequently drained into McNabey Marsh, Carquinez Strait and the adjacent waters of the Estuary. Settlement trustees fined Shell Oil US$10.8 million for damages to the affected natural resources. A portion of this settlement was used to fund an extensive study of Mason's lilaeopsis (*Lilaeopsis masonii*, Apiaceae), a rare umbel protected by the state of California impacted by the spill. The purposes of the study were to (1) document all populations of this rarity throughout the 18 200 ha of its known range, (2) characterise the plant's habitat, (3) conduct competition experiments between *L. masonii* and other commonly co-occurring taxa across a range of water salinities, (4) determine how emersion in crude oil might affect growth and reproduction and (5) determine the genetic distinctness among populations across its range, and between *L. masonii* and its common, parapatric congener, *L. occidentalis*.

Field surveys were conducted throughout its range by motorboat, canoe and on foot during a 4-year period. Results indicated that Mason's lilaeopsis is one of the most widespread 'rare' species in California (Golden and Fiedler 1991). It colonises and persists on an exceptionally wide range of substrates and soil types, from riprap rock to sand. *L. masonii* reproduces readily by seed and by fragmentation. However, it is seriously threatened by the exotic water hyacinth (*Eichornia crassipes*) that drifts on shore, smothering intertidal species. Ironically, it is also threatened by the state of California's aquatic weed herbicide program to control this exotic aquatic macrophyte (Golden and Fiedler 1991; Fiedler and Zebell 1993). Further, Fiedler and her students found that high salinity depresses growth and reproduction, with cascading effects of compromised competitive abilities (Zebell and Fiedler 1996). Crude oil depresses growth rates across a range of salinities, with depression in high-salinity environments more extreme (Zebell and Fiedler 1996). Finally, virtually no nucleotide variation in the nuclear ITS II region was apparent among populations of *L. masonii*, or between it and its common congener, *L. occidentalis* (Fiedler and Zebell 1993).

Franciscan thistle: upper watersheds/Golden Gate National Recreation Area, 2000

The Franciscan thistle (*Cirsium andrewsii*, Asteraceae) is a local endemic of the Estuary, with populations north and south of the Golden Gate. It is considered by the California Native Plant Society as a potential candidate for state and/or federal protection, but has been given no formal protection. *C. andrewsii* is a monocarpic, short-lived perennial plant of serpentinite seeps, streamsides, slope wetlands and coastal bluff habitats where the soil is nearly or entirely saturated perennially. Objectives of this rare-plant project, funded by a private branch of the federal National Park Service, were 2-fold. The first objective was to locate and map all known Golden Gate National Recreation Area populations, and the second, to describe qualitatively the population structure of each population. Results of the field effort yielded distinct differences in habitats and plant morphologies between the known populations of *C. andrewsii* in the Presidio (on the San Francisco peninsula) and those in the Marin Headlands (sites north of the Golden Gate). Specifically, Presidio populations are restricted to serpentinite seeps whereas the Marin Headlands populations are found in riverine and slope wetlands not necessarily restricted to ultramafic soils (LC Lee & Associates Inc. 2000).

Palmate bird's beak: Springtown wetlands, 2001

The Springtown Wetlands Project was conducted in the Livermore Valley under the auspices of the Alameda Flood Control District, a public regulatory agency. The Springtown wetlands are recognised as the remnants of an alkali sink scrub mosaic extending from the interior San Joaquin Valley during wetter climatic periods. These wetlands support a variety of plant and animal species at the northern and southern extent of their geographic ranges, and the ecosystem is protected in part under several state and local jurisdictions.

During a 5-month period in 2001, pollinators of the endangered palmate bird's beak (*Cordylanthus palmatus*, Orobanchaceae) and their nest sites were surveyed across 109 ha to determine potential impacts associated with channel-maintenance activities in Altamont Creek. We determined that nest sites for some native bees (e.g. *Bombus vosnesenskii* (Halictidae) and various Anthophorid taxa) were outside the proposed excavation area. However, nests of *Lasioglossum* (*Dialictus*) sp. and *Halictus tripartitus*, two frequent flower visitors, were documented in the creek banks directly downstream from the project site. Therefore, even though the proposed flood-control activities would not directly affect the primary pollinators of the endangered plant, the activities had the potential to affect pollinators and their nesting sites adjacent and downstream of the maintenance activities. A new and undescribed species of native bee (*Panurginus* sp.) also was documented as a consequence of the field study (LC Lee & Associates Inc., Center for Conservation Biology Stanford University 2002).

Soft Bird's Beak: Suisun and North Bay tidal wetlands, 2000–2004

Parasitic plants were studied by one of us (BJG) to examine how parasite–host interactions contribute to species coexistence in tidal wetlands within estuarine wetlands of northern California (Grewell 2004). A portion of this study involved an experimental population reintroduction of an endangered hemiparasite, soft bird's beak (*Cordylanthus mollis* ssp. *mollis*; Orobanchaceae) in Suisun Marsh (Fig. 1), by testing disturbance management methods to enhance the establishment success and overall fitness of this rare plant. Demographic monitoring revealed seedling life-history vulnerability influenced population growth and persistence. Ultimately, this study pointed to a critical management need for regional invasive plant control and restoration of historic tidal regions as important initial steps in recovery and restoration of an endangered plant in the Estuary (Grewell *et al*. 2003; Grewell 2004, 2005).

Diablo Range foothills rare plants, upper watershed, 2005

During spring 2005, biological surveys were conducted across a private 2000-ha parcel, located in the foothills of the Diablo Range just south of San Jose, California. The surveys were conducted to aid in the short- and long-term land-management planning processes, and to support environmental permitting for clean-up activities of contaminants on private land. Our objectives were to identify potential federal- and/or state-listed species across the project site. We documented seven rare, threatened or endangered species at the site, including two amphibians (i.e. California tiger salamander (*Ambystoma californiense*), California red-legged frog (*Rana aurora draytonii*)), one invertebrate (bay checkerspot butterfly (*Euphydryas editha bayensis*)), and four plant species (Mount Hamilton thistle (*Cirsium fontinale* var. *campylon*), Santa Clara Valley dudleya (*Dudleya setchellii*), Hall's bush mallow (*Malacothmanus hallii*) and the Metcalf Canyon jewelflower complex (*Streptanthus albidus* sspp.)). Without exception, all rare protected taxa were found in robust populations throughout the site (Blasland, Bouck & Lee Inc., unpubl. data). Of interest were ambiguous populations of a *Trifolium* morphologically intermediate between the critically endangered, once 'extinct', currently recently rediscovered *T. amoenum* and its more common congener, *T. albopurpureum* var. *dichotomum* (M. A. Vincent, pers. comm. 2005). Our findings emphasise that careful scrutiny of widespread species may yield important information to aide in the protection of closely related highly threatened taxa.

Focus

Three rare-plant projects described in greater detail illustrate the range of rare-plant projects common in the Estuary. Specifically, the Rush Ranch project involved documenting the geographic distribution and general population parameters of the federally protected Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*) for a small, local non-profit conservation organisation over a 1-year period. The Napa River project is an on-going 10-year effort that involves documenting population size and persistence of the rare *Lilaeopsis masonii* along a 10-km reach of the Napa River during the construction of a large flood-control project. This project is conducted on behalf of a public resource management agency, in part to meet its mitigation obligations incurred by a flood-control project. The third project example involves an experimental reintroduction of a rare hemiparasite in the high marsh zone of Suisun Marsh, funded over a 3-year period by a federally mandated, federal and state partnership, the California Bay Delta Authority. Each is described in full in the following text.

Case study 1: Suisun thistle—Suisun Marsh tidal wetlands/Rush Ranch Open Space Preserve

Introduction

The Suisun thistle, *Cirsium hydrophilum* var. *hydrophilum*, is an herbaceous biennial or short-lived perennial member in the thistle tribe (Cynareae) of the Asteraceae. It is an endemic of salt and brackish marshes of the Suisun Marsh ecosystem within the Golden Gate Estuary. Thirty-two *Cirsium* taxa are known in California, of which only four are non-native (Hickman 1993). More than one-third of the California *Cirsium* taxa (12/32) are listed as rare by the California Native Plant Society (CNPS) (Tibor 2001). Keil and Turner (in Hickman 1993, p. 232) remarked that the '[*Cirsium*] Taxa [are] difficult, incompletely differentiated, [and] hybridize.' This taxonomic confusion is particularly cogent for the Suisun thistle, of which, very little is known.

First described by Edward L. Greene in 1892, Suisun thistle has a complicated taxonomic history. During the 1920–1960, it was variously classified as *Carduus hydrophilus*, *Cirsium vaseyi* var. *hydrophilum* c. nov., and *Cirsium hydrophilum*, finally settling on its current classification, *Cirsium hydrophilum* var. *hydrophilum* (Howell 1949, 1970; Jepson 1925; Munz and Keck 1959; Munz 1968, Mason 1969). Between 1960 and through the 1980s, it was neither seen nor collected, and was presumed extinct until rediscovered on Grizzly Island by Dr Neil Havlik in 1989. In 1997, it was listed as '*Endangered*' under the *USA Endangered Species Act of 1973*, as amended (Federal Register 62 FR 61916; 20 November 1997) owing to its narrow distribution, low population numbers and threats to its persistence (US Fish and Wildlife Service 1997). The thistle is a highly localised rare plant thought to be in general decline (Hickman 1993; Tibor 2001).

As of the early 1990s, Suisun thistle was known to occur in three small, highly fragmented populations throughout the Suisun Marsh ecosystem, totalling less then 3000 individuals and covering less than half a hectare. The largest known population was located at Rush Ranch, a 840-ha property within the Suisun Marsh ecosystem that includes 425 ha of brackish tidal marsh (see Fig. 1). Rush Ranch is managed by the Solano Land Trust as one of the largest remnant historic brackish tidal wetlands within Suisun Marsh and the greater Estuary.

Although ~85% of the tidal wetlands in the Suisun Marsh have been impounded, little diking has occurred in the high marsh of the Solano Land Trust's Rush Ranch Open Space Preserve (Wetlands Research Associates Inc. 1989). However, regional as well as local anthropogenic disturbances have resulted in modifications to the hydrology and geomorphology of the high marsh. Large-scale manipulation of tidal marshes began during the mid-1800s with the construction of levees to reclaim land for agriculture. In addition, hydraulic gold mining in the Sierra Nevada foothills led to massive sediment accumulation throughout the Estuary and reduced tidal inflow to the high-marsh ecosystems. Additionally, Rush Ranch was operated as a ranch through the 1970s. Livestock grazing compacted soft marsh soils, altered marsh micro-topography and collapsed and infilled first-order channels. Ditching for mosquito abatement, completed during the 1980s by California Department of Fish and Game, interrupted natural drainage patterns and further infilled first-order channels (Collins *et al*. 1986).

Our study objectives were to (1) provide reliable, scientifically defensible information regarding the Suisun thistle's geographic distribution, population size and structure at Rush Ranch, (2) obtain basic autecological data and (3) provide taxon-specific land-management recommendations to Solano Land Trust. Between June and July 2003, we conducted field surveys of the 425 ha of high marsh within Rush Ranch. Surveys occurred during the flowering interval for the Suisun thistle, and, on the basis of previous field surveys, were concentrated along slough banks, tributaries and the mosquito ditch network. We mapped each occurrence with a global positioning system (GPS) (Garmin GPS 76 WAAS correction) and defined the perimeters by the use of universal transverse mercator (UTM) coordinates. We recorded the geomorphic context, hydrology, site quality, plant associates and obvious threats to population persistence. Because of the extensive number of Suisun-thistle patches, we defined subpopulations as *aggregations of individuals in similar habitat that likely experience regular and frequent gene flow*. Gene flow was estimated to be 10 m, on the basis of the average flight distance of the primary pollinators.

Methods

To estimate population density and size-class distribution data, we established 24 sample plots along eight sampling transects (30 or 90 m). We randomly placed three 1.5-m^2 sample plots in each transect, one plot in each transect third, for a total of three plots per transect. Plots were positioned in each transect by using a random number table. Within each sample plot, we measured (1) the length of the longest leaf of each individual, (2) the number of rosette leaves, (3) the height of the tallest flowering stalk on reproductive individuals, (4) the number of capitulescences and (5) the Suisun thistle canopy-cover class, and (6) recorded the name of every plant species that occurred in the plot. We also observed and collected arthropods observed on the Suisun thistle, when possible.

For our analysis, we transferred location data to a geographic information system (GIS) format and projected these onto an aerial photograph. After transferring the location data into GIS, we revised our subpopulation boundaries to those patches within 34 m or less of each other. Our GIS analyses yielded estimates of total areal coverage for each subpopulation of the Suisun thistle. Because Suisun thistle exhibits a naturally clumped distribution, we multiplied our density estimate by the total geographic extent for all patches to estimate population size. We overlaid the map of the NRCS *Soil Survey for Solano County* (US Department of Agriculture Natural Resource Conservation Service 1977) and the *Vegetation Mapping of Suisun Marsh* (California Department of Fish and Game 2000) on the geographic distribution map of Suisun thistle and analysed associations. By using our population data, we developed an average population density estimate for the entire Rush Ranch Suisun thistle population. We also derived an estimate of the total number of individuals within Rush Ranch using both density and areal coverage estimates.

Results

Results of the field survey revealed a widely dispersed population of Suisun thistle across Rush Ranch. We documented a total of 209 patches (occurrences), grouped *a posteriori* into 47 subpopulations of Suisun thistle, across ~3.46 ha (Fig. 3). Average plant density was 0.37 (0.06–2.34) individuals per 0.1 m^2 (LC Lee & Associates Inc. 2003*a*). This large range in population number is attributed to differences in the densities of plots supporting predominantly seedlings, compared with plots containing large adults. All individuals are considered to

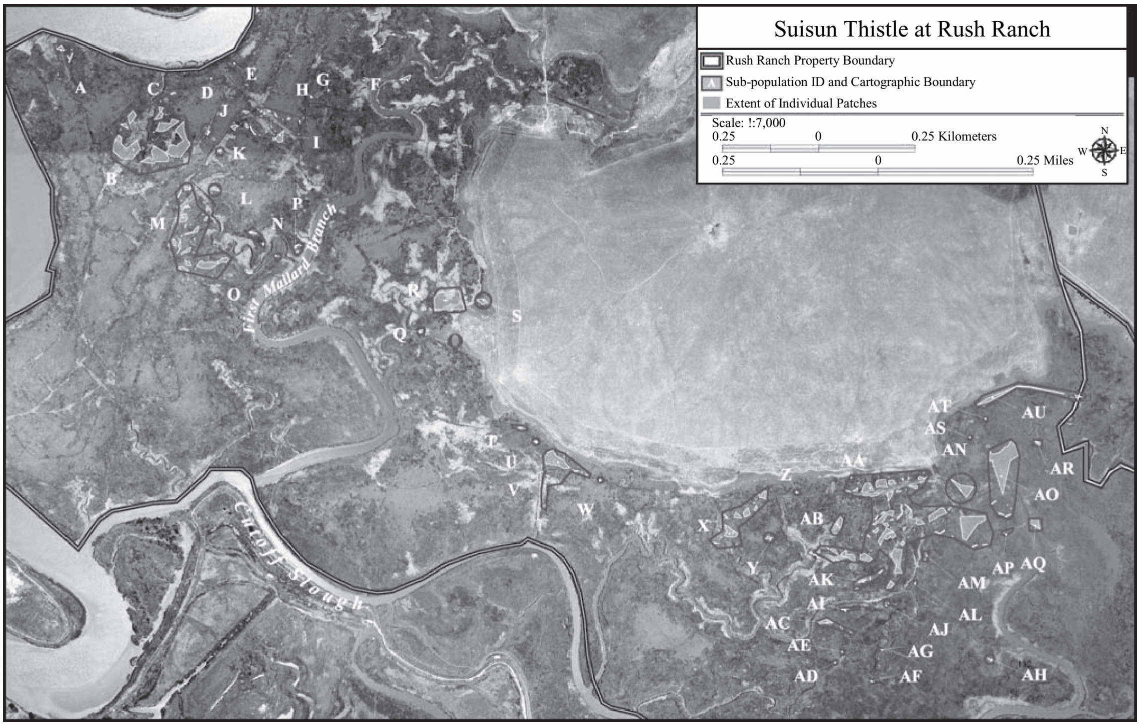

Fig. 3. Geographic distribution of Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*) at Rush Ranch, Solano County, California.

be part of a large population of ~137 500 (22 300–873 200) individuals. Most subpopulations were associated with 'mosquito ditches' (70%) and Joice muck soils (87%) (LC Lee & Associates Inc. 2003*a*). Plant associates included *Apium graveolens*, *Atriplex triangularis*, *Distichlis spicata*, *Grindelia stricta*, *Jaumea carnosa*, *Juncus balticus*, *Lepidium latifolium*, *Potentilla anserina* ssp. *pacifica*, *Rumex crispus*, *Sarcocornia pacifica* and *Schoenoplectus americanus*.

Population data revealed that the average number of capitulescences per plant was 38 (s.d. = 53), the average height of the tallest flowering stalk was 122.2 cm (s.d. = 31), 79% of the individuals were non-flowering and 21% were flowering. We found 67 seedlings, 45 non-flowering adults and 30 flowering adults across the 24 plots (LC Lee & Associates Inc. 2003*a*). Although this preliminary size-class distribution suggests that recruitment of new individuals is likely sufficient to maintain or even increase the current population size, determining population viability requires multiple years of size-class distribution and information on mortality and reproduction rates.

Discussion

Our study also revealed major threats to the long- and short-term viability of the Suisun thistle at Rush Ranch. These include (1) invasion and possible displacement of Suisun thistle by perennial pepperweed (*Lepidium latifolium*), (2) presence of a non-native phytophagous biological control weevil, *Rhinocyllus conicus*, (3) habitat destruction by feral pigs (*Sus scrofa*) and (4) the suspected hybridisation with another non-native congener, *Cirsium vulgare* (LC Lee & Associates Inc. 2003*a*).

Lepidium latifolium is an aggressive exotic that poses a serious threat to many rare plants throughout the Estuary. It creates monotypic stands, preventing recruitment of all species and concentrating salt at the soil surface (Renz 2000). At the time of our study, 85% of the Suisun-thistle subpopulations had been invaded by *Lepidium latifolium*. Feral pigs root and wallow in the high marsh and were observed to have a direct impact on the rare plants. Thirty-four per cent of the subpopulations were associated with obvious feral-pig activity. Finally, we found the thistle weevil (*Rhinocyllus conicus*) on Suisun thistle capitulescences. It is unknown the degree to which this weevil should be considered a serious threat to *C. hydrophilum* var. *hydrophilum*, despite being introduced into California more than 35 years ago to control several genera/species of weedy thistles (Kok 2002). Other researchers have found that *Rhinocyllus conicus* is present in non-target *Cirsium* species in densities similar to that in target thistles, and reduces viable seed production by 86% in a related mid-western species, *Cirsium canescens* (Louda *et al*. 1997; Turner *et al*. 1987). This and the other documented threats require further research to determine the severity of each, and their cumulative effects.

In conclusion, we determined that Rush Ranch supports a robust population of Suisun thistle. Total geographic extent of the endangered thistle was expanded from less than 0.5 ha across three sites to >3.44 ha at Rush Ranch alone. Population size increased from a few thousand plants to an average estimate of 137 500 individuals at Rush Ranch. Also, our study revealed that the ditching completed for mosquito abatement provides Suisun thistle artificial habitat and may have helped expand its distribution within the last decade. In summary, Suisun thistle appears locally abundant, despite being considered extinct a decade ago. However, major threats to population persistence remain.

Case study 2: rare estuarine-emergent plants along the Napa River/Napa Creek

Introduction

In the Napa Valley of California (refer to Fig. 1), a series of overbank flooding events by the Napa River during the last half-century have caused cumulative economic damage in excess of US$500 million (Wadsworth 1998). As a consequence, in the early 1960s, Napa County officials endorsed and approved financial support to the US Army Corps of Engineers for the development and implementation of the Napa River/Napa Creek Flood Protection Project (Flood Protection Project). The Flood Protection Project was initiated in 1965 with the authorisation by the USA Congress of a large-scale construction project along a 10-km reach of the main stem of the Napa River and a 2.25-km reach of Napa Creek within the vicinity of the City of Napa. Implementation of the Flood Protection Project began in 1999–2000. The Flood Protection Project addresses multiple interests and project goals in restoring the riparian and flood-plain ecosystems of the Napa River.

In late winter 2001, the Napa County Flood Control and Water Conservation District initiated an investigation of the distribution of rare-plant species in the lower reaches of the Napa River and Napa Creek ecosystem. The study included (1) documentation of all rare-plant populations, (2) characterised potentially suitable, but unoccupied, habitat for possible mitigation (e.g. transplantation) sites, (3) preparation of a mitigation strategy for potential impacts to all rare, threatened or endangered plant species, (4) preparation of a monitoring plan for plant species of conservation concern and (5) annual monitoring of two plant species of conservation concern within the contract reaches, *Lilaeopsis masonii* and *Lathyrus jepsonii* var. *jepsonii* (Fabaceae).

Mason's lilaeopsis

Mason's lilaeopsis (*Lilaeopsis masonii*) is an herbaceous perennial member of the Apiaceae family. Thirteen species have been described for the genus and all are characteristic of marshy or aquatic habitats in North and South America; however, one species occurs in Australia (Affolter 1985). Two species, *L. occidentalis* (western lilaeopsis) and *L. masonii*, occur along the Pacific Coast of the North American continent. *Lilaeopsis masonii* is restricted to inland, intertidal estuary habitats of the Golden Gate Estuary, whereas *L. occidentalis* is characteristic of brackish marshes of the Pacific coast, from Marin County, California, north to the Queen Charlotte Islands, British Columbia (Affolter 1985). The genus *Lilaeopsis* has long been recognised as taxonomically difficult owing to the vegetative simplicity of its taxa, and consequently the similarity among various more distantly related taxa. Also as a consequence of its morphology and growth habit, Mason's lilaeopsis is easily overlooked in its native habitat. It is protected formally by the state of California under the California Endangered Species Act, but not by the federal government.

Mason's lilaeopsis is a diminutive, somewhat non-descript perennial that spreads laterally by rhizomatous growth. Leaves form 'tufts' borne along the horizontal rhizome or at the apex of vertical rhizomatous branches. Branches vary in length, from 1.5 to 7.5(–15.0) cm long, and from (0.2–)0.4 to 1.2 mm wide. Leaves are terete, linear or filiform, and bear septa not easily seen unless the leaf is held up to the light. Small white to greenish flowers occur in simple umbels, each bearing between three and eight flowers. The flowering period is long, extending from April to October, with fruits maturing between June and October (Affolter 1985). Because of the very small seed size (~1 mm), recruitment by seed germination and establishment is not documented thoroughly for this rare species, although it is well known to occur.

Affolter (1985) determined that members of the genus *Lilaeopsis*, including *L. masonii*, can and do spread rapidly by their creeping rhizomes. He also suggested that vegetative reproduction could provide a means of dispersal within a water body. Affolter wrote '[D]ispersal by lateral growth of rhizomes is not a rapid process, but it could certainly account for movement over several decimetres in the course of a growing season. Dispersal over greater distances would occur when the plants became uprooted and free-floating.' (Affolter 1985, p. 23).

With respect to sexual reproduction, the very small flowers of all *Lilaeopsis* taxa make traditional breeding-system experiments difficult. However, small flower size is characteristic of self-compatibility in flowering plants, itself a feature that facilitates long-distance dispersal (Baker 1955). Experiments on this genus by Affolter (1985) determined that *Lilaeopsis* plants are either self-compatible or apomictic, with the former breeding system characteristic of many Apiaceae (Bell 1954). Therefore, the founding of new populations of Mason's lilaeopsis is unlikely to be limited by the absence of mates (i.e. pollen) or pollinators.

Fruit of *Lilaeopsis* appears particularly suited for water dispersal because of the presence of spongy tissue in the mericarp. Affolter (1985) found that seeds of *Lilaeopsis* could float for 8 months or longer and still germinate. As such, *Lilaeopsis* fruits are likely to be transported across water bodies to considerable distances. Dispersal of *Lilaeopsis* also is facilitated passively through attachment of the seeds to the feet and feathers of waterfowl through mud or mucilage, or both.

Jepson tule pea

Jepson tule pea (*Lathyrus jepsonii* var. *jepsonii*) is an herbaceous member of Fabaceae. It is a scrambling perennial found almost exclusively in coastal and estuarine marshes of the Sacramento–San Joaquin Delta ecosystem. Climbing, winged stems that commonly spread over adjacent plants characterise *L. j.* var. *jepsonii*. Flowers are typical of the pea family and range in colour from pink to light purple. This species can be distinguished from its more common sister taxon, *L. j.* var. *californicus* (bluff pea), because of relatively more robust, glabrous stems of *L. j.* var. *jepsonii*. An individual delta tule pea can grow up to 2.5 m in length. Otherwise, very little is known about the biology or systematics of *L. j.* var. *jepsonii*. This tule pea is not protected formally either by the state of California or by the federal government.

Methods

Field teams of two to three botanists performed surveys on foot of the lower Napa River ecosystem during low tide when vegetation at and below the high-tide line along the riverbanks is exposed. For purposes of yearly monitoring, the team developed a simple field protocol for identifying distinct populations of Mason's lilaeopsis within the lower Napa River ecosystem. The primary criterion that distinguishes distinct *Lilaeopsis* patches is ~15 m or more unoccupied substrate. This 'rule' is primarily because the simple, turf-like life form of Mason's lilaeopsis makes it extremely difficult to distinguish distinct populations at certain occurrences. Further, some populations may consist of a few small patches (ramets) separated by only a metre or less, whereas other populations may be viewed best as a continuous mat of intertwined ramets that stretch for many metres without a break in continuity of vegetative cover.

The field team documented each Mason's lilaeopsis patch population by using a California Native Species Field Survey Form as required by the state of California Resources Agency Natural Diversity Database. Data recorded included (1) exact location (e.g. UTM coordinates using a GPS unit) and other information about the population's location, (2) phenology of the population at the time of visitation, (3) general habitat description, (4) site information including a relative score for site quality, (5) current surrounding land use, (6) visible disturbances or possible threats to the rare plant population and (7) a record of photographs of the population and surrounding habitat taken during the field visit. On completion of the fieldwork, location data (e.g. UTM coordinates) were transferred into a GIS format (ArcGIS 9.0; ESRI 2004).

Results

Mason's lilaeopsis is commonly found among older, well-established rhizomes of the California and hard-stem bulrushes (*Schoenoplectus californicus* and *S. acutus* var. *occidentalis*, respectively) along the Napa River bank margins where high light levels prevail. During the 5 years of monitoring, plant species most commonly associated with Mason's lilaeopsis in the littoral zone of the Napa River ecosystem were *Cotula coronopifolia*, *Lythrum hyssopifolium*, *Eleocharis parvula*, *Schoenoplectus californicus*, *Distichlis spicata*, *Isolepis cernuus* and *Rumex crispus*. During our 2001–2005 monitoring efforts, we documented the number of *L. masonii* populations ranging from 65 to 82, with areal-extent estimates between 400 and >975 m^2 (Fig. 4 trends chart) (LC Lee & Associates Inc. 2002*a*, 2002*b*, 2003*b*, 2004).

Throughout our 5 years of monitoring, we documented only a single *Lathyrus jepsonii* var. *jepsonii* population. Plant associates in the project reach included *Symphoricarpos molli*, *Foeniculum vulgare*, *Brassica nigra* and *Raphanus sativus*.

Discussion

Both the total number of patch populations and total areal extent of Mason's lilaeopsis within the lower Napa River remained relatively robust over the 5-year monitoring interval, falling within the range of mitigation targets established by state resource-management agencies (Fig. 4). Specifically, the mitigation project target was articulated as 69 total populations within the study area or a total areal extent of 375 m^2, with the total not declining 10% for two consecutive years during the 10-year monitoring period.

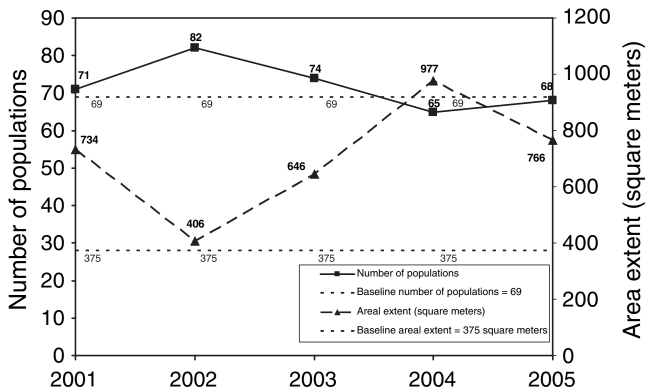

Fig. 4. Trends of population number and areal extent for Mason's lilaeopsis (*Lilaeopsis masonii*) from 2001 to 2005 within the Napa River/Napa Creek Flood Protection Project, Napa, California.

Conservation recommendations for Mason's lilaeopsis should be based on a landscape-level approach to resource management. Mason's lilaeopsis appears to be structured as a metapopulation within the Lower Napa River ecosystem. Location of a particular patch may be as important as size in determining the role of a patch in maintaining the larger metapopulation. As such, large patch populations are not necessarily more important than smaller ones for the persistence of the metapopulation. In this context, small populations on small clods of soil that break from the riverbank and disperse along the Lower Napa River may be instrumental in founding new populations within adjacent suitable habitat. All patch populations, no matter how large or small, may be important to the larger metapopulation and the persistence of Mason's lilaeopsis within the Napa River ecosystem (Fig. 4).

In summary, Mason's lilaeopsis patch populations have remained robust, despite both natural and anthropogenic disturbances within the project reach. Geographic extent of individual patch populations varies widely from year to year, with annual variation ranging from ~185 to 280 m^2 (Fig. 5). Observations indicate that patch populations located in relatively higher-disturbance zones (meanders) appear to have greater number of extinction and colonisation events. However, even after 5 years of close monitoring, patch size/yearly growth remains unpredictable (Blasland Bouck & Lee Inc. 2005).

Case study 3: *Cordylanthus mollis* ssp. *mollis*—experimental reintroduction in Suisun Marsh

Introduction

Cordylanthus mollis ssp. *mollis* (Orobanchaceae; ex-Scrophulariaceae) is a hemiparasitic plant endemic to high-elevation tidal marshes of Suisun Marsh and the North Bay of California's Golden Gate Estuary. Although capable of photosynthesis, hemiparasites receive crucial host subsidies of water, nitrogen, fixed carbon and mineral compounds through haustorial organ connections to vascular tissues in host-plant roots (Press 1989; Press *et al.* 1999). *Cordylanthus* species

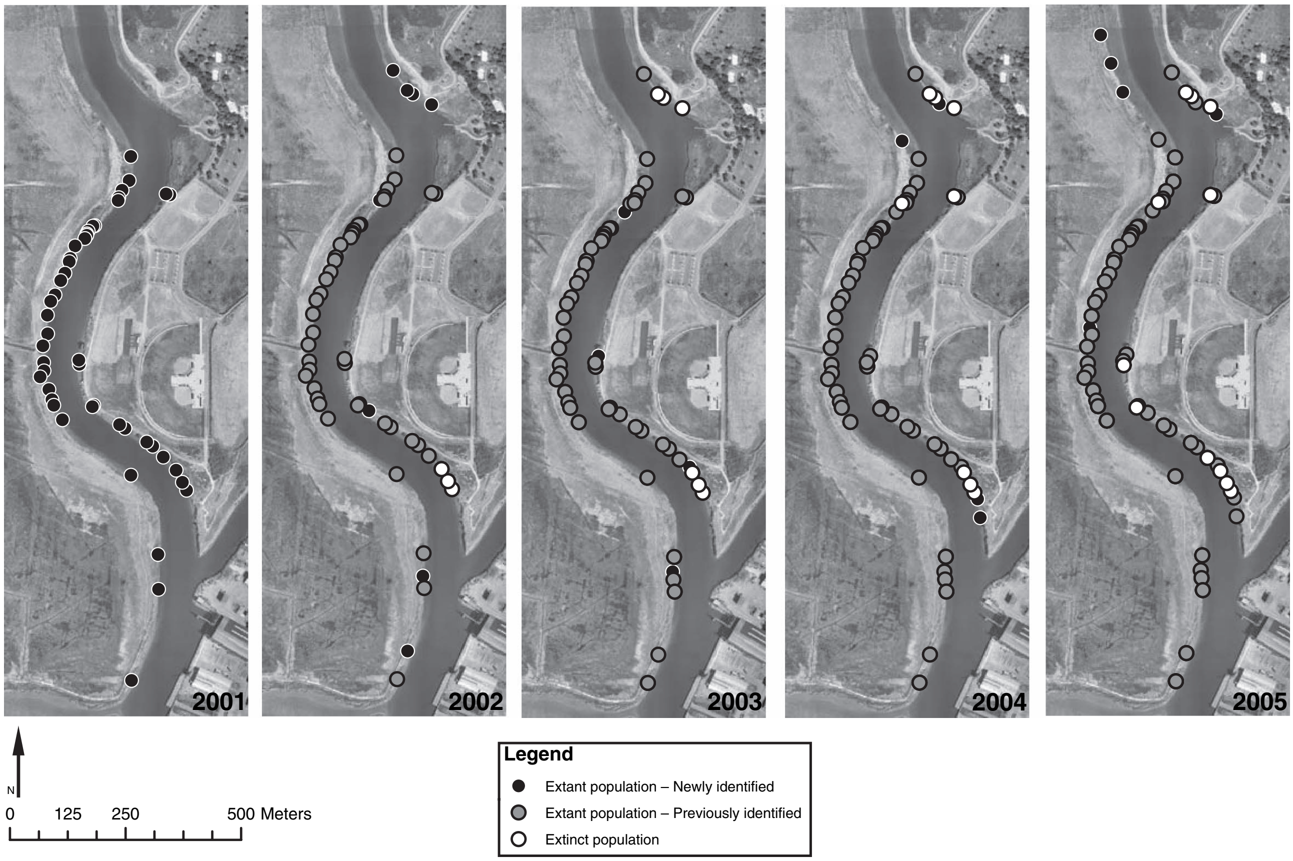

Fig. 5. Geographic location of Mason's lilaeopsis (*Lilaeopsis masonii*) populations documented from 2001 to 2005 within the Napa River/Napa Creek Flood Protection Project, Napa, California.

acquire resources from a variety of available hosts, rely on a host for survival in field conditions, but are not host-specific (Chuang and Heckard 1971, 1972, 1973). However, parasite fitness and persistence may hinge on appropriate host associations and restoration and recovery of native parasitic plants may require consideration of host-community structure and composition, and host quality to sustain parasite populations (Marvier and Smith 1997). Root hemiparasites are often dependent on disturbance-created gaps for recruitment in otherwise closed-canopy host communities (Marvier and Smith 1997; Petrü and Lepš 2000). Because natural disturbance processes have been highly altered in tidal wetlands, management intervention may be required to provide recruitment gaps for rare-plant recovery.

Historic accounts indicate *C. m.* ssp. *mollis* is an anthropogenic rarity that is endangered owing to the loss and degradation of tidal wetlands (Ruygt 1994). Listed as *Endangered* by the United States government since 1997, *C. m.* ssp. *mollis* is targeted for population recovery (US Fish and Wildlife Service 1997). Because the recovery of rare plants often requires the creation of new populations in order to decrease extinction risk, the California Bay Delta Authority (CALFED) Ecosystem Restoration Program funded this research to provide science-based guidance for rare-plant restoration as a contribution towards water-management goals for native species recovery and to improve San Francisco Bay–Sacrament-San Joaquin Delta ecosystem quality (Grewell *et al*. 2003). Research objectives were to (1) census extant populations and investigate habitat factors critical to *C. m.* ssp. *mollis*, (2) experimentally test methods of population reintroduction, (3) track plant demographics to identify critical life stages and identify threats to population persistence and (4) recommend a conservation monitoring plan. Public outreach was conducted to communicate research results to resource managers and the interested public. In this paper, we report results from a subset of this project, with focus on experimental tests of restoration techniques. Experimental questions were (1) whether timing of seeding and creation of disturbance gaps improve rare-plant establishment and (2) whether reintroduced plant fitness is comparable to the demographic performance of natural reference populations?

Methods

The restoration experiment was conducted at the Rush Ranch tidal wetland within the historic range and habitat of the species (refer to Fig. 1). Extant reference populations in nearby estuarine wetlands were identified for comparative monitoring. Recognising the potential effects of local selection on restoration donor populations (Knapp and Rice 1994, 1998), seeds were collected from the two large natural populations 1.2 and 3.7 km from the restoration site to match source populations with local environmental conditions and to maximise the evolutionary potential of the reintroduced population.

To evaluate timing of seeding and creation of canopy gaps (disturbance) as restoration techniques, eight experimental blocks divided into 12 1-m^2 plots were randomly located along a transect within the intertidal zone supporting the appropriate host-plant community. Restoration planting treatments were arranged in a randomised block design and included a factorial combination of canopy-gap disturbance at two levels (canopy-gap disturbance, no disturbance) and planting time at six levels (November, December (fall), March, April, May (spring), and no sow). One-metre buffers were established around the perimeter of each block. To establish disturbance treatments, 20 10-cm gaps per 1-m^2 plot were created in a random mosaic pattern by clipping aboveground plant-community biomass at ground level and removing clipped material and any litter present to expose bare ground in the gap. Plots were re-clipped as needed to maintain gaps through the seedling-emergence period.

Following Fink and Zedler (1991), pre-sowing seed treatment and a fixed sowing density of 300 seeds m^{-2} were implemented following restoration planting guidelines for endangered *Cordylanthus maritimus* ssp. *maritimus* in southern California wetlands. Lots of 300 seeds per experimental treatment were subjected to an overnight freshwater soak before planting. Seeds were sown by hand in designated planting treatment months. To reduce potential loss of seeds to birds or tides, seeds were pressed gently into the soil surface but not completely covered with soil. Densities of surviving reproductive adults were measured response variables in 2001 and 2002. Supplemental analyses of host-plant community composition and structure are reported elsewhere (Grewell *et al*. 2003; Grewell 2004). Planting-month treatments were pooled for final analyses by season (spring, fall) as there were no within-season differences in density response. The response data were 4th-root transformed to meet normality and variance assumptions required for the linear model. The effects of disturbance treatments and timing of seed introduction on established *Cordylanthus* density response the first and second year following seed introduction to restoration plots were analysed with repeated-measures ANOVA by using the general linear model (GLM) in Systat (SPSS 1999).

Restoration plots were visually inspected weekly for seedling emergence. Following emergence, 100 seedlings were tagged in RUSH restoration control plots and three reference populations (HILL, BBAY, BSRA) to evaluate reintroduced population fitness. Plant growth (height) and life stage were recorded weekly, and at senescence tagged plants were dissected and branch, flower and seed-capsule counts, and pre-dispersal seed-granivory rates were recorded. Granivory rates were quantified as the proportion of seed capsules with evidence (Lepidopteran larvae within capsules, frass, and/or boreholes in reproductive tissues) of pre-dispersal predation. At each population site, mature seeds were counted from a random subsample of 25 capsules from different plants for fecundity calculations. Population means of rare-plant fitness indicators, including log-transformed height, branches, flower and seed-capsule production, and fecundity; and arcsin (square-root) transformed pre-dispersal granivory rates were analysed with MANOVA by using the GLM procedure in Systat (SPSS 1999).

Results

Disturbance management had a positive effect on the established density of reproductive *C. m.* ssp. *mollis* 1 and 2 years following seed introduction to restoration plots, and the interactive effect of disturbance and season of sowing was significant as disturbance enhanced establishment of rare plants in spring-seeded plots (repeated-measures ANOVA, Table 3). By the second season, the initial time of sowing did not influence reproductive-plant density (Table 3). *C. m.* ssp. *mollis* establishment was spatially variable (significant block effect, Table 3), suggesting microhabitat conditions affect restoration success.

Results of MANOVA confirm significant differences in fitness between *C. m.* ssp. *mollis* in restoration and reference populations (Wilks' $\lambda = 0.162, P \leq 0.0001$, Fig. 6). Plant growth was higher at RUSH and BBAY than at BSRA and HILL, but branching did not vary among populations. Flower and seed-capsule production were highest in the RUSH restoration population, and pre-dispersal granivory was not detected over the first 2 years of restoration establishment. Granivory by a larval seed predator (*Saphenista* sp., Tortricidae) was elevated at HILL and BSRA, depressing overall fecundity in these reference populations. The significant differences were primarily due to a negative correlation between seed-capsule production and growth compared with granivory levels and overall fecundity across populations. That is, the pattern of seeds produced per plant, as affected by plant growth and pre-dispersal granivory, varies among populations.

Discussion

This experimental reintroduction of an endangered plant to its historic range was intended to provide scientific information to restoration managers for larger-scale endangered-plant recovery efforts. The short-term results suggest that it is possible to establish a population of *C. m.* ssp. *mollis* in a restoration site, but confirmation of success will require long-term monitoring. Pollinators were attracted to flowers within the new population in the first season, but pre-dispersal seed predators present in reference populations were not detected during this study. Fecundity of the reintroduced plants may decline in the future, if these animals enter the restoration food web. Disturbance-

Table 3. Repeated measures ANOVA results of the effect of gap-disturbance management (disturbance), time of seeding (season) and their interaction on established density of *Cordylanthus mollis* 1 and 2 years following seed introduction to restoration plots

Source of variation	SS	d.f.	MS	*F*	*P*
Between Subjects					
Disturbance	10.73	1	10.73	14.00	≤0.0001
Season	94.23	2	13.02	16.99	≤0.0001
Disturbance × Season	6.66	2	3.33	4.35	0.016
Block	91.14	7	13.02	16.99	≤0.0001
Error	63.61	83	0.77		
Within Subjects					
Disturbance	7.01	1	7.01	27.13	≤0.0001
Season	0.68	2	0.34	1.31	0.276
Disturbance × Season	1.28	2	0.64	2.48	0.090
Block	26.70	7	3.81	14.76	≤0.0001
Error	21.44	83	0.26		

gap manipulation, coupled with direct seeding into appropriate host communities, shows promise as a reintroduction technique. In the present study, *C. m.* ssp. *mollis* responded with improved demographic performance. However, canopy-gap management also resulted in high rates of exotic-plant invasions that were linked to rare-plant seedling mortality (Grewell 2004).

The significant block effect observed in the reintroduction experiment emphasises the importance of microsite conditions. Measurements of aboveground biomass across the study site indicated better rare-plant establishment in areas with higher aboveground biomass of a potential host plant and greater flood frequencies (Grewell *et al*. 2003). The potential host-plant identity and biomass are important screening criteria for *C. m.* ssp. *mollis* reintroduction sites. Potential host-plant communities with unsuitable exotic hosts and communities with extremely low biomass production before parasitism may not successfully support the additional parasite load.

Restoration of sustainable ecosystems before attempting to restore populations within the range of an endangered plant is imperative. Furthermore, land managers must be vigilant and respond to emerging threats (i.e. non-native species invasions, hydrologic alterations) to population persistence. Reintroduction techniques for *C. m. mollis* must be coupled with invasive-plant control to improve re-establishment and population-recovery efforts.

Lessons learnt

This retrospective on 20 years of rare-plant field research, monitoring and survey work has yielded a surprising number of insights. We present these below, organised by the type of insight, or lesson learnt, as follows: those that relate to science of rare plants, those that relate to the logistics of studying rare plants in a highly urbanised estuary, and those that relate to project costs.

In this latter regard, what has emerged relative to overall project expenditures is that rare-plant field research is as likely to be inadequately funded as it is unlikely to be lavishly funded. The former is the consequence of often limited public funds for conservation-related work, or the typical ‘shoe-string’ budgets of non-profit nature-conservation organisations. Similarly, rare-plant research, monitoring and survey work is rarely funded on the scale of cutting-edge molecular ecology. This is in part because, more often than not, rare-plant research does not require the costly expenditures associated with laboratory analysis, and

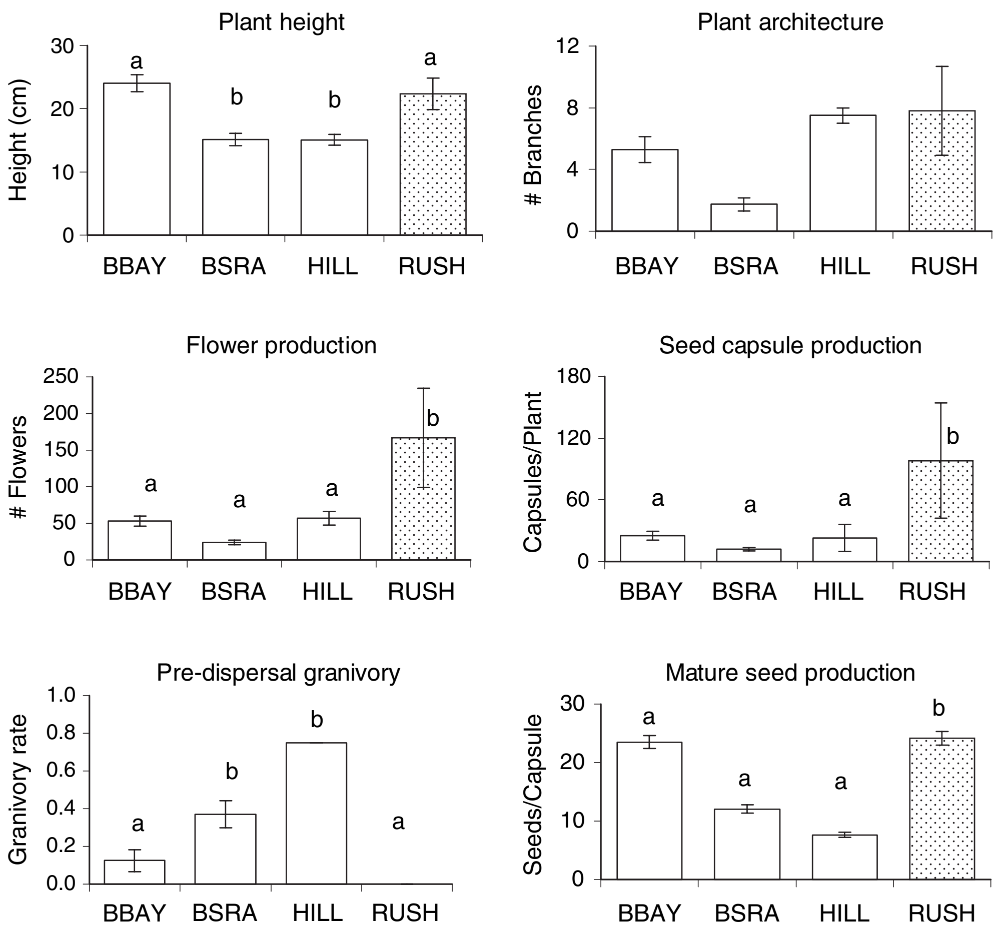

Fig. 6. Fitness measures of *Cordylanthus mollis* plants that survive to reproductive maturity in 2002 at the Rush Ranch restoration and three reference population sites. Bars represent means ± s.e. Shaded bars represent the restoration population. Fitness metrics that are different among sites at $P = 0.05$ are marked by different lower-case letters.

in part because rare-plant biology is rarely a high priority for funding agencies and organisations.

Lessons learnt relative to science of rare-plant biology

(1) *Rare species persist*. All projects have revealed a larger geographic distribution and larger population sizes of rare plants.
(2) *Habitat considerations are paramount*. Understanding habitat requirements facilitates predicting distribution and abundance, facilitating protection efforts.
(3) *Reintroduction is possible*. On the basis of extensive and intensive short-term studies, it is possible to reintroduce rare plants successfully. Using an array of reference sites is the key.
(4) *Restore habitat/ecosystem functions first*. Rare-plant populations are not likely to persist unless ecosystem functions are restored before reintroduction of the rare plant.
(5) *Monitoring with management-driven objectives is critical*. Rare-plant populations are not likely to persist unless an on-going assessment of threats (i.e. exotic species invasions, changes incritical physical processes) is coupled with conservation actions and adaptive management to improve populations status.

Lessons learnt relative to logistics of conducting field research on rare-plant biology

(1) *Take a community approach*. Looking at multiple species of conservation concern in a community (plants and animals, regardless of the level of protected status) is more efficient for conservation efforts than is looking at single species, and is likely to result in comparatively more information. This approach also has implications for reducing overall project costs (see (1) below, in regard to economics of rare-plant biology).
(2) *Commit in the long term*. Multi-year projects do not have to be more expensive. Instead, spreading slightly more resources over slightly longer time can yield much more information. In other words, a marginal increase in effort yields a great deal information.
(3) *Choose your taxon carefully*. Some listed species may not be as rare or as threatened as originally thought. Careful consideration as to which taxon to study is warranted.
(4) *It pays to look*. There are advantages in taking the time to look, and in integrating observations across the landscape; to learn by difference. Discoveries abound.

Lessons learnt relative to economics of rare-plant biology

(1) *Multi-year/multi-species projects are comparatively more economical*. In terms of overall conservation efforts, significant cost savings are achieved by increasing the number of species studied and the length of time of the study (see (1) above, in regard to logistics of conducting field research on rare-plant biology).
(2) *Work in linear systems is comparatively expensive*. Rare plants in linear systems (e.g. restricted to riverbanks) are more expensive overall (i.e. per year, per person, per species).
(3) *Under-funded projects yield relatively less*. Under-funded projects are likely to yield little useful information. This is particularly true when funding is limited to census of rare annual plants. Annual-plant population sizes fluctuate widely over time, and merely counting/mapping plants does not inform us of the biological status of the populations, information which is critical for conservation (Pavlik 1994).
(4) *Use funds wisely*. Allocation of rare funding resources could be more equitable, better targeted towards species that are truly rare, or towards species that are significant evolutionary units.

Remaining issues/conclusions

Several troubling issues have emerged from our long-term studies in the field. First, it appears that public agencies are protecting some species that, we have come to learn, are neither rare nor threatened. This is largely because during the early listing process in the late 1970s and early 1980s, when species were provided formal protection under state and federal laws, species that we knew little about were listed. Thirty years later, we know that such taxa are more widespread, exist in greater population numbers or are protected in parks and preserves. Yet, these taxa are still afforded protection under state and federal laws. There is little opportunity to 'de-list' or down-grade species, thereby releasing funds for highly endangered taxa. This argument, however, does not discount the critical importance of formal protection of rare species.

Second, after molecular genetic analysis, we have learned that certain protected species are not genetically distinct (and morphologically indistinguishable) from common and more widespread species. Exploring ITS2 sequences, Fiedler and Zebell (1993) determined that the state-protected *Lilaeopsis masonii* exhibits virtually no variation among populations, nor is it distinguishable from its very widespread, and closely related congener, *L. occidentalis*.

Third, one infraspecific taxon may be afforded protection while its sister taxon is not. Uncertain or faulty taxonomic delimitation, as well as old or outdated species concepts, can therefore default to protecting a taxon that either is not a distinct taxonomic unit, or not in need of protection.

Last, there are significant evolutionary units that require protection, field study, monitoring and reintroduction, but that are simply unrecognised and therefore unprotected (a situation likely to be true everywhere). Ultimately, we believe it is incumbent that rare-plant specialists work with conservation organisations, as well as with the variety of entities that fund rare-plant work, in order to carefully choose species that are most likely to benefit from our attention, both in the field and in the laboratory.

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